INTRODUCTION TO MAPPING NOXIOUS WEEDS

The primary objective of weed surveying and mapping is to accurately identify and delineate land with populations of unwanted plants. These surveys are conducted so scientists and managers can

- predict those areas potentially subject to weed invasion
- understand the biology of the invasion process and determine means by which weeds spread
- develop, implement, and evaluate weed management plans
- assess the economic impact of weed invasion, and
- increase public awareness, education, and weed management efforts.

Weed survey information is collected and compiled into maps showing the distribution and severity of infestation. Weed monitoring involves repetitive surveys to track weed populations over time. A standardized system of weed surveying and mapping is necessary to provide consistently reliable information that can be compared from year to year. Further, a standardized system allows weed survey data to be incorporated into a statewide weed survey database for the production of statewide noxious weed maps.

In Montana, representatives from federal, state and county agencies—as well as industry and private individuals—developed guidelines and standards for a statewide noxious weed survey and mapping system. This publication introduces the *Montana Noxious Weed Survey and Mapping System.* The first sections of the publication discuss the standardized mapping procedures developed for the system, including type and scale of base maps to be used, how to designate infested areas on the map, symbols to use for percent cover, codes for indicating weed species, and the type of drawing instruments to use when hand-drawing weed infestation boundaries on base maps. It also includes standards to use when mapping weed biological control release and recovery sites.

The final section provides additional information on data recording methods, including use of hand-drawn maps, computer mapping systems and the Global Positioning System (GPS). This section also discusses combining data collected by different methods, software compatibility considerations and digital base layers available for computer mapping.

The specific objectives for this system are listed at the right.

This effort represents the beginning of a noxious weed inventory for the state of Montana that can be continually updated. As more weed managers participate in the program, a greater portion of the state will be accurately mapped. The ultimate goal of this project is a complete inventory of all noxious weeds in the state, a process that will take many years.

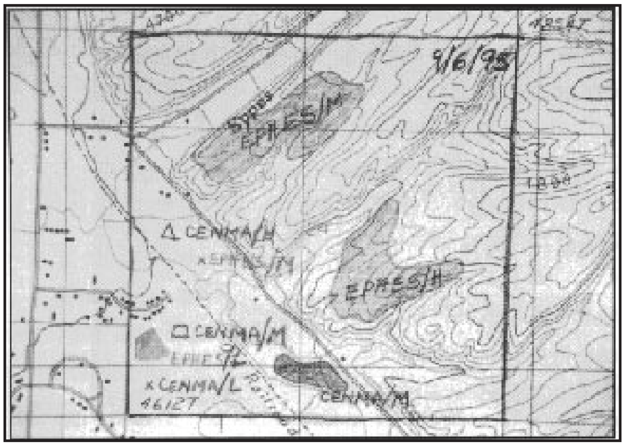
The specific objectives of the *Montana Noxious Weed Survey and Mapping System* are:

- to determine and record locations of noxious weeds in Montana,
- to accurately calculate total number of acres infested for each weed on the state noxious weed list,
- to determine how fast noxious weeds are spreading by comparing weed inventories over time.

Statewide Mapping Procedures for Weeds

Type and Scale of Base Maps

Weed survey maps may be created by hand-drawing infestation boundaries on base maps (Figure 1), using a computerized mapping system such as ArcView or County-CAD (Figure 2), or by collecting location coordinates of weed infestations using Global Positioning System (GPS) technology (Figure 3). For those who are hand-drawing weed infestations on base maps, USGS 1:24,000 scale (7.5 minute series) maps should be used. This scale is appropriate for weed management planning and can easily be consolidated into 1:100,000 scale county and statewide maps.



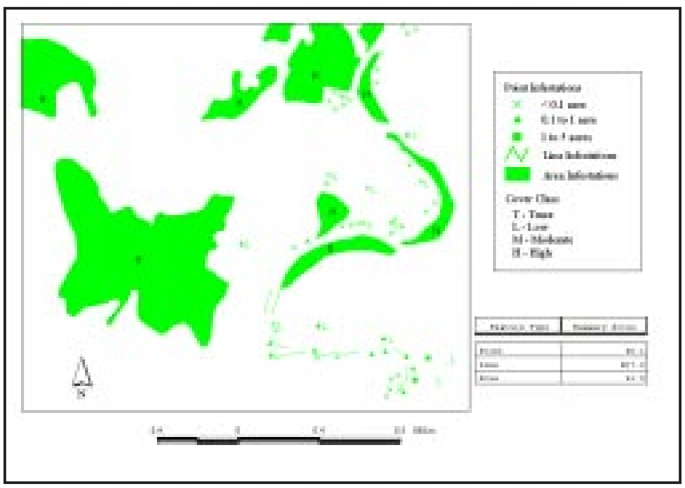


Figure 1 (above): Topographic map with hand-drawn weed inventory. Figure 2 (below): Computer-generated weed map.

In counties where detailed soil surveys have been completed, aerial photographs may be available (contact the Natural Resources Conservation Service for information). Aerial photographs show good detail and can be used to locate your position and draw in surveyed weed infestations. However, unless they are geodetically corrected[1], it will be difficult to incorporate the infestations into statewide maps because they cannot be digitized. Orthophotos are geodetically corrected aerial photographs. They are distortion-free and can be digitized. If the aerial photographs are not geodetically corrected, the weed delineation could be drawn on them and then later transferred to a topographic map, which can be digitized.

Weed managers have also considered using satellite imagery for base maps. At this time, most available satellite imagery does not have high enough resolution to be used for weed mapping. Satellite imagery with high spatial resolution will probably be available at a reasonable cost sometime in the next five to ten years.

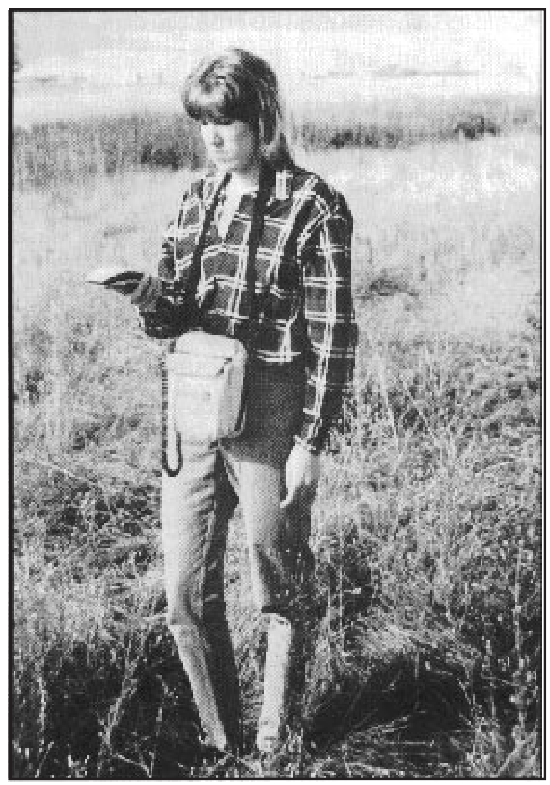


Figure 3. Collecting weed data using GPS.

[1] There are changes in scale across an aerial photograph due to the particular configuration of platform altitude, camera system alignment and topography. The image must be rectified so it matches with a "correct" map of the earth. This process is called rubber-sheeting and results in a geodetically correct image that can be reliably used in a Geographic Information System.

Drawing Instruments

Prismacolor® Verithin® color pencils should be used to designate weed infestations on hand-drawn maps

A problem with hand-drawn maps is that mapping accuracy can be affected by the size of the drawing instrument. A line 1/32 of an inch wide (1 mm) on a 1:24,000 scale USGS map will cover a width of 62.5 feet on the ground. If a felt pen is used to mark the perimeter of a weed infestation, it may appear larger than if a No. 2 pencil is used. Therefore, a standardized size of drawing instrument should be used to delineate weed infestations. For the *Montana Noxious Weed Survey and Mapping System*, Prismacolor® Verithin® color pencils were chosen. If the pencils are kept sharp, the line width is about 1/64 of an inch (0.5 mm). This line width represents about 30 feet on a 1:24,000 scale map. The pencils come in sets of 24 colors (15 of these will be used to designate Montana's category 1, 2 and 3 noxious weeds), have strong, long-lasting lead and are light-fast and waterproof. They work well with both paper maps and mat acetate or Mylar overlays. They are erasable. Prismacolor® Verithin® pencils can be purchased at many office supply and art supply stores. Mat acetate and Mylar can be purchased at most art supply stores and copy centers. A convenient size to use with 7.5 minute topographic maps is 18" x 24". The overlay should be smaller than the topographic map so it can be taped to the map. Be sure to use drafting tape to avoid tearing the map. Mylar overlays should be sprayed with a map fixative so pencil markings don't smear. Topographic maps usually have four "+" marks that can be used for lining up the overlay on the map. These should be marked carefully on the overlay.

Symbols for Designating Infested Acres

Before mapping weed infestations, ***outline*** the survey area on the map and write the ***date*** of the survey in the upper right corner of the outlined area. Areas inside the survey boundary without size and location designations will be considered weed free. Map the infested areas using the symbols at the right to designate the size and locations of the infestations (symbols should be centered over the infestation sites—see Figures 1 and 2, page 2).

In addition to drawing the line on the map, record the following information:

1) **Width of line.** Record the average width of the weed infestation in meters or yards next to the line drawn on the base map.

2) **Direction of weeds from line.** Next to the average line width value, write an L, R, or C depending on where the weeds are located (i.e., are the weed infestations to the left, right or centered on the line you have drawn on the base map?).

Designate Each Weed Species by the WSSA Five-letter Code and the Appropriate Color

Noxious weeds should be designated by their Weed Science Society of America-approved computer codes from the ***Composite List of Weeds***, Revised 1989, available from WSSA, 1508 West University Ave., Champaign, IL 61821-3133, 1-800-627-0629 for $10 (shown for some common Montana weeds in Table 1). Each plant on Montana's state noxious weed list should also be color coded according to Table 1. Standardized color coded designations by weed species facilitate map interpretation.

Infestation Size

x = less than 0.1 acre

△ = 0.1 to 1 acre

□ = 1 to 5 acres

 = areas larger than 5 acres. Outline these directly on the map.

~ = infestations that follow linear features such as roads and streams. Designate these by drawing lines on the map.

Table 1. Five-letter codes and color designations for the 15 Montana noxious weeds

Noxious weed species Common name	Scientific name	WSSA 5-letter code	Designated color (Berol Verithin/ white box)[1]	Designated color[1] (Prismacolor Berol Verithin/black box)[1]
Category 1[2]				
leafy spurge	*Euphorbia esula*	EPHES	Green (739)	Peacock Green (739)
Canada thistle	*Cirsium arvense*	CIRAR	Tuscan Red (746½)	Tuscan Red (746½)
Russian knapweed	*Centaurea repens*	CENRE	Carmine Red (745)	Terra Cotta (745½)
spotted knapweed	*Centaurea maculosa*	CENMA	Lavender (742½)	Parma Violet (742½)
diffuse knapweed	*Centaurea diffusa*	CENDI	Light Grey (734½)	Warm Grey (734½)
field bindweed	*Convolvulus arvensis*	CONAR	Pink (743)	Deco Pink (743)
whitetop (hoary cress)	*Cardaria draba*	CADDR	Sky Blue (740½)	Peacock Blue (740½)
Dalmatian toadflax	*Linaria dalmatica*	LINDA	Canary Yellow (735)	Canary Yellow (735)
St. Johnswort (goatweed)	*Hypericum perforatum*	HYPPE	Olive Green (739½)	Olive Green (739½)
sulfur cinquefoil	*Potentilla recta*	PTLRC	Orange (737)	Orange (737)
Category 2[3]				
dyer's woad	*Isatis tinctoria*	ISATI	Grass Green (738)	Grass Green (738)
purple loosestrife	*Lythrum salicaria*	LYTSA	Purple (752)	Dahlia Purple (752)
purple loosestrife	*Lythrum virgatum*	LYTVI	Black (747)	Black (747)
Category 3[4]				
yellow starthistle	*Centaurea solstitialis*	CENSO	Ultramarine (740)	Ultramarine (740)
common crupina	*Crupina vulgaris*	CJNVU	Violet (742)	Violet (742)
rush skeletonweed	*Chondrilla juncea*	CHOJU	Scarlet Red (744)	Scarlet Red (744)

[1] *Because of a change in ownership there are two versions of the Prismacolor® Verithin® pencil packs. The original set comes in a white box. The new set comes in a black box. There are slight differences in the color names and numbers. Please use the colors listed in the column that refers to your box. Please choose different colors for mapping other county-designated noxious weeds not listed here.*

[2] *Category 1 noxious weeds are weeds that are currently established and generally widespread in many counties of the state. Management criteria include awareness and education, containment and suppression of existing infestations and prevention of new infestations. These weeds are capable of rapid spread and render land unfit or greatly limit beneficial uses.*

[3] *Category 2 noxious weeds have recently been introduced into the state or are rapidly spreading from their current infestation sites. These weeds are capable of rapid spread and invasion of lands, rendering lands unfit for beneficial uses. Management criteria include awareness and education, monitoring and containment of known infestations and eradication where possible.*

[4] *Category 3 noxious weeds have not been detected in the state or may be found only in small, scattered, localized infestations. Management criteria include awareness and education, early detection and immediate action to eradicate infestations. These weeds are known pests in nearby states and are capable of rapid spread and render land unfit for beneficial uses.*

Indicate Percent Cover by Species

Mapping systems for weed management planning must be simple, and the data must be easy to collect. Weed cover has been determined to be the most important attribute to be collected for the statewide system. Cover may be estimated as a percent of the ground covered by a particular weed species. Estimates are categorized by cover class.

Cover class should be indicated directly on the map next to the infested acres symbol. Use the symbols at the right to indicate infestation cover class.

Additional attributes (such as weed density or growth stage) are optional and can be noted on either base maps or clear overlays. Alternatively, this information could be written on a separate piece of paper or entered into a field computer database. If you are recording information in a separate place (not on the map), write a ***site number*** identifying each weed infestation on the map, so the information can be linked to the appropriate weed infestation.

Infestation Cover Class

T = (Trace; rare): less than 1% cover (Figure 4).

L = (Low; occasional plants): between 1 and 5% cover (Figure 5).

M = (Moderate; scattered plants): between 5 and 25% cover (Figure 6).

H = (High; fairly dense): between 25 and 100% cover (Figure 7).

Density (optional)

Note number of plants per square yard or square meter

Growth Stage (optional)

S = Seedling

B = Bolt

Bd = Bud

Fl = Flower

SS = Seed Set

M = Mature

Figure 4. Trace: <1% cover

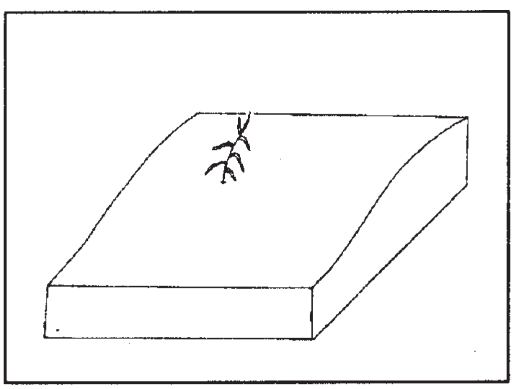
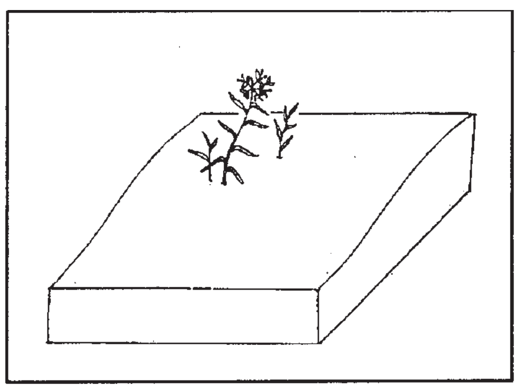


Figure 5. Low: 1-5% cover



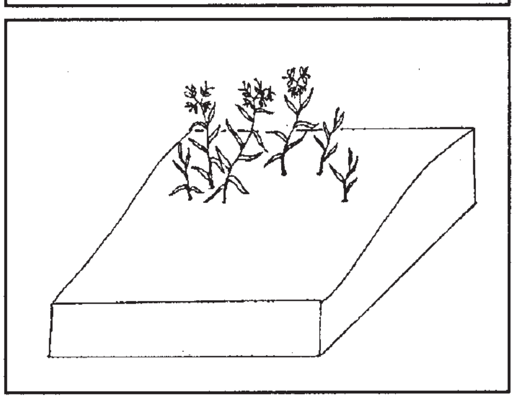


Figure 6. Moderate: 5-25% cover

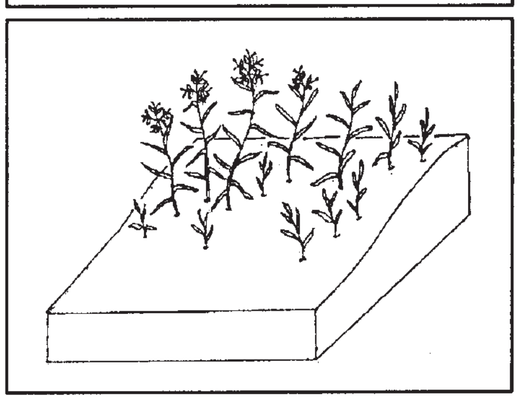


Figure 7. High: 25-100% cover

STATEWIDE MAPPING PROCEDURES FOR BIOCONTROL RELEASES AND RECOVERIES

Symbols for designating releases and recoveries

Ⓡ = biocontrol release

Ⓥ = biocontrol recovery

Biological control data have not yet been incorporated into the *Montana Noxious Weed Survey and Mapping System*. However, if you plan to map biological control releases and recoveries, we suggest using the following standards that were developed by a working group of weed supervisors and scientists. This will allow biocontrol data to be incorporated into the statewide system in the future.

Biocontrol mapping should be done on USGS 1:24,000 scale (7.5 minute series) maps or Mylar overlays. Geodetically corrected orthophotos may also be used. Please refer to the section on **Type and Scale of Base Maps** under **Statewide Mapping Procedures for Weeds** for more information (p. 2).

Using a No.2 lead pencil, map the releases and/or recoveries using the symbols at the left to designate their locations (symbols should be centered over the release or recovery sites).

Unique Site Codes for Identifying Releases and Recoveries

Write a code (to uniquely identify the release or recovery site) next to the symbol using the following format: *YYSSSAAA*. *YY* refers to the last two digits of a year, for example, *1997* would be coded *97*. *SSS* is a 3-digit code for site number, designated by the agency doing the release or recovery according to their own coding system. *AAA* is a 3-character code that identifies the agency or county weed district doing the release or recovery according to the codes listed in Tables 2 and 3, below and at right.

This unique code will be used to link the following additional information to the site: species of the biocontrol agent designated by the codes listed in Table 4 (p. 8), and species of the target weed designated by the WSSA codes listed in Table 1 (p. 4). These two additional items can be written on the map or on a separate paper or form, and submitted to the statewide weed mapping system along with the map.

Other optional information can be collected and linked to the sites by the unique code, but may not be used by the statewide system. Examples of optional information are date of the release or recovery, number of organisms released, climatic conditions, slope, moisture, landowner, notes, etc.

Table 2. Three-letter agency codes

Agency	Code
Montana Department of Natural Resources and Conservation	DNR
Montana Department of Transportation	MDT
Montana Department of Fish, Wildlife and Parks	FWP
Montana Department of Agriculture	MDA
Private agency or individual	PRI
US Department of Energy	DOE
US Army Corps of Engineers	ACE
US Department of Defense	DOD
US Department of Transportation	DOT
USDA-Agricultural Research Service	ARS
USDA-Animal and Plant Health Inspection Service (APHIS)	APH
USDA-Forest Service	UFS
USDA-National Park Service	NPS
USDA-Natural Resources Conservation Service	NRC
USDI-Bureau of Indian Affairs	BIA
USDI-Bureau of Land Management	BLM
USDI-Bureau of Reclamation	BOR
USDI-Fish and Wildlife Service	FWS

Using and Submitting Data

Using Weed Survey Data for County-Level Management

Weed data and maps can be used to develop a county weed management plan based on land-use objectives. Critical management and environmental information such as weed species present, extent and severity of weed infestations, and environmental conditions (e.g., sensitive areas) can be determined from maps. Maps can also be used to direct the implementation of the weed management plan. They show the location of areas needing attention and can be used to set priorities, estimate needs for equipment, supplies and labor, and to guide action crews. Once the plan is implemented, maps can be used to evaluate weed management strategies by comparing initial maps with subsequent maps to find out how weed infestations have changed over time. This information can be used to help identify portions of the plan which do not meet management

Table 3. Three-character county FIPS codes

County	Code	County	Code	County	Code
Beaverhead	001	Granite	039	Powell	077
Big Horn	003	Hill	041	Prairie	079
Blaine	005	Jefferson	043	Ravalli	081
Broadwater	007	Judith Basin	045	Richland	083
Carbon	009	Lake	047	Roosevelt	085
Carter	011	Lewis & Clark	049	Rosebud	087
Cascade	013	Liberty	051	Sanders	089
Chouteau	015	Lincoln	053	Sheridan	091
Custer	017	McCone	055	Silver Bow	093
Daniels	019	Madison	057	Stillwater	095
Dawson	021	Meagher	059	Sweetgrass	097
Deer Lodge	023	Mineral	061	Teton	099
Fallon	025	Missoula	063	Toole	101
Fergus	027	Musselshell	065	Treasure	103
Flathead	029	Park	067	Valley	105
Gallatin	031	Petroleum	069	Wheatland	107
Garfield	033	Phillips	071	Wibaux	109
Glacier	035	Pondera	073	Yellowstone	111
Golden Valley	037	Powder River	075	Yellowstone NP	113

Table 4. Five-letter biocontrol agent codes

Species	Code	Species	Code
Knapweeds		**Poison hemlock**	
Agapeta zoegana (moth)	AGAZO	*Agonopterix alstroemeriana* (moth)	AGOAL
Bangasternus fausti (weevil)	BANFA	*Septoria convolvuli* (fungus)	SEPCO
Chaetorellia acrolophi (fly)	CHAAC	*Tyta luctuosa* (moth)	TYTLU
Cyphocleonus achates (weevil)	CYPAC	**Purple Lythrum (Loosestrife)**	
Fusarium avenaceum (fungus)	FUSAV	*Hylobius transversovittatus* (beetle)	HYLTR
Larinus minutus (weevil)	LARMI	*Galerucella calmariensis* (weevil)	GALCA
Larinus obtusus (weevil)	LAROB	*Galerucella pusilla* (weevil)	GALPU
Metzneria paucipuntella (fly)	METPA	*Nanophyes brevis* (weevil)	NANBR
Pelochrista medullana (moth)	PELME	*Nanophyes marmoratus* (weevil)	NANMA
Pterolonche inspersa (moth)	PTEIN	**St. Johnswort**	
Sclerotinia sclerotiorum (fungus)	SCLSC	*Agrillis hyperici* (beetle)	AGRHY
Mesoanguina (Subanguina) picridis (nematode)	MESPI	*Aplocera plagiata* (moth)	APLPL
Sphenoptera jugoslavica (beetle)	SPHJU	*Chrysolina hyperici* (beetle)	CHRHY
Terellia virens (fly)	TERVI	*Chrysolina quadrigemini* (beetle)	CHRQU
Urophora affinis (fly)	UROAF	*Zeuxidipolis giardi* (fly)	ZEUGI
Urophora quadrifasciata (fly)	UROQU	**Thistles**	
Leafy Spurge		*Cassida rubiginosa* (beetle)	CASRU
Aphthona abdominalis (flea beetle)	APHAB	*Cheilosia corydon* (fly)	CHECO
Aphthona cyparissiae (flea beetle)	APHCY	*Hadroplontus (Ceutorhynchus) litura* (weevil)	HADLI
Aphthona czwalinae (flea beetle)	APHCZ	*Larinus planus* (weevil)	LARPL
Aphthona. flava (flea beetle)	APHFL	*Rhinocyllus conicus* (weevil)	RHICO
Aphthona. lacertosa (flea beetle)	APHLA	*Trichosirocalus horridus* (weevil)	TRIHO
Aphthona. nigriscutis (flea beetle)	APHNI	*Urophora cardui* (fly)	UROCA
Chamaesphecia crassicornis (moth)	CHACR	*Urophora solstitialis* (fly)	UROSO
Chamaesphecia hungarica (moth)	CHAHU	**Toadflaxes**	
Dasineura nr. capsulae (fly)	DASCA	*Brachyperolus pulicarius* (beetle)	BRAPU
Hyles euphorbiae (moth)	HYLEU	*Calophasia lunula* (moth)	CALLU
Oberea erythrocephala (beetle)	OBEER	*Eteobelea intermediella* (moth)	ETEIN
Rhizoctonia solani (fungus)	RHISO	*Eteobelea serratella* (moth)	ETESE
Spurgia esulae (fly)	SPUES	*Gymnetron antirrhini* (weevil)	GYMAN
Spurgia capitigena (fly)	SPUCA	*Gymnetron linariae* (weevil)	GYMLI
Field Bindweed		*Mecinus janthinus* (weevil)	MECJA
Aceria malherbae (mites)	ACEMA		

objectives and to adjust management strategies.

Maps can also be used to predict those areas potentially subject to weed invasion and guide surveys of land adjacent to infested areas. In addition, they can be used as communication tools for public awareness and education, and for calculating the economic and ecological impacts of noxious weed invasion.

Submitting Data to the Statewide Weed Mapping System

Weed survey data collected according to the procedures described in this publication can be incorporated into the *Montana Noxious Weed Survey and Mapping System* statewide weed database. The consolidated statewide database is the basis for maps showing areas in Montana infested with noxious weeds, and for calculations of the total number of acres known to be infested with each weed. The spread of noxious weeds will be tracked by comparing weed inventories from year to year. This information facilitates assessment of weed management programs and can help identify areas with successful weed management strategies.

Statewide weed maps will be based on a scale of 1:100,000 and show county boundaries, towns, major roads and waterways, as well as locations of weed infestations. Weed data may be submitted to the statewide system as hand-drawn infestation boundaries on topographic maps or orthophotos, or as digital files in one of the formats described under "Software Compatibility Considerations" (p. 19). All data submitted to the statewide system must be accompanied by a completed "Metadata Form" (Appendix A). Hand-drawn maps will be digitized, then incorporated into the statewide geographic database. The *Montana Noxious Weed Survey and Mapping System* uses ARC/INFO and ArcView software to maintain the weed inventory and produce maps.

Education and training will be available each year for interested weed managers and supervisors. Contact us for more information.

Where to Submit Weed Data and Maps

If you plan to collect data according to the *Montana Noxious Weed Survey and Mapping System* standards and submit it to the statewide weed database, please contact us to obtain a *Weed Mapping Handbook*, which explains data collection procedures in more detail and provides additional reference materials. All submitted data must be accompanied by a completed "Metadata Form" (see Appendix A). Questions about the system should be directed to Diana Cooksey at (406) 994-5684, Elizabeth Roberts at (406) 994-6211 or Roger Sheley at (406) 994-5686. All are with the Department of Plant, Soil and Environmental Sciences, MSU-Bozeman, Bozeman, MT 59717. You may also access the *Montana Noxious Weed Survey and Mapping System* Web site at http://www.montana.edu/places/mtweeds

If you have **questions** about the Montana Noxious Weed Survey and Mapping System, call

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Data Recording and Data Management Considerations

Data Recording Methods

Several approaches may be used to record weed survey data. Infestation boundaries can be hand-drawn on base maps, entered manually into a computer mapping system, or delineated using a Global Positioning System (GPS) unit and then imported into a computer mapping program. Standardized mapping procedures for hand-drawn maps are described in the first four sections of this bulletin. The same basic principles apply to computer mapping and GPS mapping, but the actual mapping approach and details of the mapping process are necessarily different and more complex. You can obtain a weed mapping handbook that describes specific details of each method by contacting us at the address listed on page 9 or by filling out an electronic order form on our Web site.

Figure 8. Attribute data

Geographic information can be described by features, attributes and values. Features can be points, lines or polygons that represent real-world entities. Attributes are characteristics of a map feature. Each attribute has a set of possible values. For instance, the set of possible values for the attribute, weed species, includes leafy spurge, Canada thistle, Russian knapweed, spotted knapweed, diffuse knapweed, field bindweed, and so on. Here is an example of a map feature and its attributes and values.

Feature	Attributes	Attribute Values
Weed area (#12)	Weed species	Leafy spurge (EPHES)
	Infestation size	less than 0.1 acre (x)
	Cover class	Moderate (M)
	Growth stage	Flower (Fl)

Hand-Drawn Maps

The least costly method in terms of hardware required is to hand-draw weed infestations on base maps that show towns, roads, waterways, topography, land survey boundaries and other geographic features. It is critical to consistently use the same scale and type of base map so data can be compared from year to year. As discussed under **Statewide Mapping Procedures** (page 2) USGS 7.5 minute series (1:24,000 scale) topographic maps work well for weed surveys. Aerial photographs, if available, may be used to record the location of weed infestations. However, locations must later be transferred to a topographic map that is geodetically correct. Orthophotos are ideal for recording infestations, but they are expensive and are often not available.

Include attribute data (see Figure 8, left) such as species, size of infestation and cover class on the map by using the symbols described on page 3. Purchasing the 7.5 minute maps for an entire county can be expensive. To avoid having to use new maps each year, weed infestations can be drawn on mat acetate or mylar overlays. This allows easy comparisons of weed infestations over time. Each year's map should be carefully labeled.

Weed surveyors must be able to read maps accurately. Seasonal employees must be trained to develop map-reading skills. In addition, take care to use the appropriate pencil type (so the drawn lines are always the same size) to mark weed infestations as described on pages 3-5.

Computer Mapping Systems

Computer mapping systems, or geographic information systems (GIS), are becoming the standard tool for all types of mapping. A GIS is traditionally defined as a computer based system used to capture, store, edit, manipulate, analyze and display geographically referenced data[2]. Computer based mapping systems provide a consistent framework for handling geographic data. Maps can be created and updated quickly, eliminating tedious map drawing by hand. Once base maps are created, it is easy to maintain and overlay periodic weed inventories. Maps can be printed or plotted at different scales to fit different documents, and high quality output can be produced using a computer mapping system.

Geographic information systems provide a framework for data analysis. Weed survey data can be related to other digital data layers such as precipitation, temperature, soils and vegetative cover (see discussion under **Digital Base Layers Available for Computer Mapping**, page 20). Together, these data can provide information for evaluating weed management plans, predicting areas vulnerable to weed invasion, understanding the biology of the invasion process and for assessing the economic impact of weed invasion.

Required hardware

A computer with a 486 processor or better (a Pentium is ideal) and sufficient RAM (at least 16-32 MB) is recommended for operating most computer mapping programs. Since GIS files can become quite large, the mapping computer should have at least a 250 megabyte hard disk. A 500 megabyte or larger hard disk is preferable, especially if GPS files will be incorporated into the database. An input device, such as a digitizer or scanner, may be used to enter data into the system. Output devices, such as printers, plotters and film recorders, may be used to generate presentation quality maps. Other peripherals, such as a CD-ROM drive, may be needed for accessing data and/or programs. Some hardware (plotters, scanners, digitizers) may be shared among agencies to minimize individual costs or allow the purchase of higher quality equipment.

Mapping software

Computer mapping software are divided into four types: computer aided drafting (CAD), desktop mapping, desktop GIS and GIS. Within each category, there can be significant variation in software features and capabilities. CAD programs are primarily designed for computer cartography (production of maps and diagrams) rather than spatial analysis (analyzing, querying and manipulating geographically referenced data). Unlike a good GIS, most CAD programs cannot accommodate complex analysis functions. CAD programs are usually considered graphic design packages, whereas geographic information systems are considered spatial analysis packages. CAD files can usually be

[2]Geographically referenced data are simply data that are related to specific geographic locations. For instance, a weed infestation has a geographic location (a real-world location on the ground that can be referenced by map coordinates such as UTM or latitude/longitude) with associated attribute data (species, cover class, etc.).

converted to GIS layers for spatial analysis. Desktop mapping and desktop GIS programs fall somewhere in between CAD and GIS, and the distinction between desktop mapping and desktop GIS is not always clear. Desktop mapping programs provide graphic design tools specifically for mapping and include some spatial analysis capabilities. Desktop GIS programs generally include more sophisticated spatial analysis tools than desktop mapping programs, but are not as powerful as full-blown GIS programs. Many mapping and CAD programs meet the needs of most weed mapping projects. If complex spatial analysis is required by your application, a desktop GIS or a GIS is the appropriate tool. When choosing mapping software, be aware of its capabilities and limitations to ensure that it meets your requirements and that the data can be exported in a format compatible with the statewide system. Also, be sure to check hardware required to run the software. Most importantly, find out what mapping software package other groups in your agency or local government are already using, and base your choice on compatibility with their systems, so data and other resources can be shared.

Entering data into a computer mapping system

Data can be entered into computer mapping programs in several ways. Most of the software listed below allow display of a base map for reference, and weed infestations can be drawn on-screen. The quality and accuracy of base maps available for each program is an issue that must be addressed. Most computer mapping programs also allow digitizing of weed infestations and other features using a digitizing tablet, or importing data collected using a GPS receiver. If you are using a program that can display a reference map in the background, be sure the map can be correctly registered. This will require entering real-world coordinates for identifiable points on the map. Only the most sophisticated GIS programs can correct for distortion errors that may exist in background maps.

Digitizing tablets are the most common devices for extracting spatial information from paper maps. A digitizer is essentially

Table 5. Some examples of widely-used computer mapping software in each category

CAD *Minimal spatial analysis*	**Desktop Mapping** *Some spatial analysis*	**Desktop GIS** *Complex spatial analysis*	**GIS** *Most complex and powerful spatial analysis*
CountyCAD	Atlas GIS	ArcView GIS 3.0	ARC/INFO
ArcCAD	MapInfo		GRASS
CAD Overlay	ArcView 2.1		IDRISI
	Maptitude		Intergraph
	Instant Survey		PAMAP

an electronic drafting table. The hardware consists of a tablet and stylus, or cursor, with cross hairs. The paper map to be digitized is taped onto the tablet and is digitized by moving the cursor across the map and clicking to record features. The cursor sends an electronic signal to a fine wire grid under the tablet surface, and the tablet reads the clicks as pairs of x-y coordinates. In order for the computer to convert the x-y coordinates into map coordinates (such as latitude/longitude or UTM) several control points must be entered at the beginning of the digitizing session. These control points reference points on the map to points on the grid. Points selected for control points should be the most reliable points on the map. Coordinates at benchmarks are ideal if you can get them. Most surveyors can look them up, or you can get the information from the National Geodetic Survey (NGS). These first order points give excellent accuracy from the field and can be expected to be well placed on the map. Corners and + marks on 7.5 minute USGS topographic maps may also be used for control points.

Slow, careful digitizing results in accurately recorded features and requires less editing, especially when the data are being incorporated into a GIS that uses topology[3]. It can take two hours of editing to fix one hour of sloppy digitizing. One must also be aware of other potential problems with digitizing. Most maps are not drafted for the purpose of digitizing, and all maps contain a certain amount of error that is entered into the mapping program or GIS. Inherent errors directly related to error in the source map cannot be corrected by the GIS. In addition, paper maps can be unstable. Maps can shrink and swell with changes in temperature and humidity between digitizing sessions, causing additional error. Points or tics of known locations can minimize map deformation error. If the study area being digitized is large, requiring the use of adjacent maps, map sheet boundaries can cause discrepancies in the database. For example, two map sheets may not match where a stream crosses the map boundary. This can happen when maps are drawn in different years since streams change from year to year. Edge matching of adjacent maps can be done automatically in sophisticated GIS programs.

In most cases, an already existing computerized base map can be obtained, and only the weed infestations are digitized from a hand-drawn map. The location of weed infestations may be designated by points, areas (polygons or regions), or lines (arcs). Attribute data such as weed species, size of infestation and cover class can be recorded on the map along with the geographic locations of weed infestations. These attributes can

[3]Topology defines the spatial relationships of features by defining their properties. It includes information about what labels are connected to which features, how points are connected to each other, and which points and lines make up which polygons. This topological information allows a GIS to perform spatial relationship functions like overlaying polygons, buffering lines and polygons, determining if a line is within a polygon, and determining the proximity of one feature to another. Use of topological data structures differentiates true geographic information systems from desktop mapping, computer-aided drafting and presentation graphics software.

A common misconception:

A **large scale** map does not show a larger area; in fact, it shows a small area in great detail. A **small scale** map shows a larger area in less detail.

When data captured at different scales are combined, the resulting database is only as accurate as the smallest (least detailed) scale used for input.

be linked to the locations of weed infestations in the computer mapping system.

Base maps on which weed infestations are drawn should be geo-referenced. A geo-referenced map contains points that can be tied (referenced) to specific points on the earth's surface, usually by latitude/longitude, UTM, or state plane coordinates. Although it is possible to digitize a map using a user-defined coordinate system, it will be difficult, if not impossible, to overlay data from subsequent years and to combine it with data from other sources if the base map is not geo-referenced. If the weed infestations are drawn on USGS 1:24,000 scale maps, good control points are usually available. Orthophotos are geo-referenced aerial photographs and can be used for digitizing.

A GIS or computer mapping program allows combining source documents generated at different scales, but this can cause misleading results. The scale at which data are captured represents their level of accuracy. For instance, let's say a transportation layer is digitized from a 1:24,000 scale map and a hydrography layer is digitized from a 1:100,000 scale map, then the two layers are combined in a GIS. The roads from the transportation layer are more detailed than the waterways from the hydrography layer since the scale of the source document was larger. The combined database is only as accurate as the least detailed scale used for input (in this case, 1:100,000). The less detailed 1:100,000 waterways cannot accurately be represented at the more detailed 1:24,000 scale.

Global Positioning System

The global positioning system (GPS), developed by the U.S. Department of Defense, is a satellite-based system used to locate positions anywhere on the earth, 24 hours a day. The system can be used for any application that requires location coordinates. Weed managers can use GPS to map the perimeter of weed infestations or record the location of an infested area and navigate back to the same site later.

A GPS receiver on the ground uses radio signals transmitted by at least four satellites to compute a 3-dimensional position. For national defense reasons, the U.S. Government scrambles the radio signals, so the position calculated by a single GPS receiver can be in error by 30 to 100 meters or more. This intentional degradation of the satellite signals is called Selective Availability or S/A. Other sources of GPS error include ionospheric and atmospheric effects, receiver clock error, electrical interference and multipath[4] effects.

A procedure called differential correction, or differential GPS (DGPS), can reduce the error introduced by S/A and other sources (not including multipath). This requires a reference receiver, often called a base station, operating at a known location. Since the reference receiver "knows" where it is, it can measure the error in the positions calculated from the satellite signals and transmit the error corrections to the "roving" GPS receiver. When the correction data are transmitted to the roving receiver via radio signals, the process is called "real-

[4]Multipath effects occur when the GPS satellite signal takes more than one path to reach the GPS antenna by bouncing off a building or other object. This causes error in the range measured between the GPS satellite and the GPS receiver on the ground.

time" differential correction (real-time DGPS). In this case, corrected positions are shown on the roving receiver's display and, if a file is being collected, it will contain corrected positions. If the base receiver is not capable of transmitting real-time corrections, the process can be accomplished in a "post-processed" mode. In this case, both the base and roving receivers collect files that are later processed together using computer software. The corrections from the base file are applied to the roving receiver file during processing, resulting in a new file with the corrected positions. Navigating to a known position using a single (autonomous) GPS receiver will only get you to within a range of about 30 to 100 meters of the true position. If you are navigating using real-time differential correction you can get within a few meters of the true position with most mapping grade receivers. More information about both real-time and post-processed differential correction data is available from our office (see p. 9).

GPS receivers can be used to collect points, lines (arcs), and areas (polygons or regions). GPS position coordinates are reported in latitude, longitude and height above the ellipsoid model of the earth, but can be converted to many different coordinate systems (UTM, state plane, etc.) for display and mapping. Attribute data can be collected along with geographic coordinates. Many GPS systems include software to design databases (sometimes called data dictionaries) and attribute collection menus that make it easy for the user to collect attribute data along with feature boundaries.

Attribute collection requires that a field computer be connected to the GPS receiver. Many GPS receivers have built-in computers and attribute collection menus can be programmed into the receiver. Figure 9 shows part of the menu system, or data dictionary, installed in a Trimble GeoExplorer GPS receiver. Figure 10 (next page) shows the series of menu choices a user would encounter when entering data for a **Weed Point** using a receiver programmed with the *Montana Noxious Weed Survey and Mapping System* data dictionary. Similar menu choices appear when the user selects **Weed Area** or **Weed Line**.

Mapping grade GPS receivers are available from several manufacturers, including Trimble Navigation, Motorola, Magellan, SOKKIA, Corvallis Microtechnology, Rockwell and many others. For weed mapping, your roving receiver should be capable of storing a file that can be downloaded and differentially corrected. Many government agencies operate GPS base stations and may provide correction files for post-processed differential correction. If you plan to use files from an operating

Figure 9. Part of weed survey menu system programmed into a GPS receiver

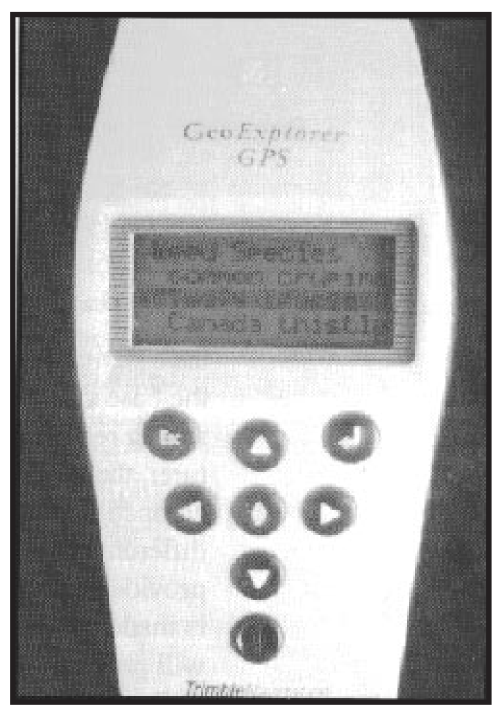

Figure 10. Weed Survey Data Dictionary

Weed Point →	Date	
	Species →	leafy spurge,[EPHES]
		Canada thistle,[CIRAR]
		Russian knapweed,[CENRE]
		spotted knapweed,[CENMA]
		diffuse knapweed,[CENDI]
		field bindweed,[CONAR]
		whitetop/hoary cress,[CADDR]
		Dalmatian toadflax,[LINDA]
		St. Johnswort/goatwd,[HYPPE]
		sulfur cinquefoil,[PTLRC]
		dyer’s woad,[ISATI]
		s/purp.lythrum,[LYTSA]
		v/purp.lythrum,[LYTVI]
		yellow starthistle,[CENSO]
		common crupina,[CJNVU]
		rush skeletonweed,[CHOJU]
		Other, [O]
		Unknown ,[U]
	CoverClass→	Trace/rare,[T]
		Low/occasional plts., [L]
		Moderate/scatt.plts.,[M]
		High/fairly dense,[H]
	SizeInfest→	< .1 acre,[X]
		.1 to 1 acre,[T]
		1 to 5 acres,[S]

base station, determine the manufacturer of the base station receiver. If you purchase a roving receiver from the same manufacturer, the base and rover files will be compatible and your rover files can be differentially corrected using software provided by the manufacturer. If your rover is made by a different manufacturer, you will probably have to convert the base files to Receiver Independent Exchange (RINEX) format before they can be used to differentially correct your rover data. Make sure your differential correction software can use a RINEX base file. If not, the rover file has to be converted to RINEX format and then differentially corrected using software provided by the base station manufacturer. In this situation, any attribute data stored in your roving receiver file will be lost because the RINEX format supports conversion of position data only. If you need to use a RINEX conversion, make sure you test it thoroughly before purchasing a receiver.

Some companies, such as Differential Corrections, Inc. (DCI) and ACCQPOINT Communications Corp., offer differential correction services via FM radio on a subscription basis. To use these services, your GPS receiver must be capable of receiving real-time correction data. Additionally, you must purchase an FM radio receiver that is compatible with your GPS receiver. Check with the service to determine which GPS receivers are compatible. Further, make sure that the differential correction signals can be received in the area you plan to survey. Other companies such as Omnistar and RACAL provide differential corrections via their own satellite systems. To receive their signals you must purchase a special satellite receiver as well as the subscription service. The signals from satellites are generally available over a widespread area. Your GPS receiver must be able to receive the correction data from the satellite receiver and apply those corrections to the data it collects. Some companies offer an integrated GPS/satellite correction receiver so you don’t have to purchase a separate GPS receiver. Just be sure the system will allow attribute data collection and can provide any other features you need.

Another option is to set up your own base station to transmit real-time corrections to a GPS unit that is capable of receiving the correction data, or to correct rover data in post-processed mode. If you plan to do this, make sure the manufacturer can supply all the necessary components including base and rover receivers, radios or satellite correction receivers (if using real-time correction) and differential correction software (if using post-processed correction). Additional information about the basics of GPS for weed mapping is available from our office (see p. 9).

Several important issues must be addressed when making maps from GPS data, especially when combining GPS generated maps with data from other sources, such as USGS topographic maps or existing digital base maps.

Datums, projections and coordinate systems

A datum is a model that describes the size and shape of the earth. It includes a selected mathematical representation of the earth's surface (called an ellipsoid), the designation of an initial reference point on that ellipsoid, and other items that more fully define the model. Coordinates for points are then computed from these initial quantities and are dependent upon the datum used.

USGS topographic maps made before 1988 use the NAD-27 horizontal datum which is based on the Clarke 1866 reference ellipsoid. Because there were some measurement errors and intentional distortion in the NAD-27 datum, it was redefined and recomputed in the mid-1980s, resulting in the NAD-83 datum, which uses the GRS-80 reference ellipsoid. The differences between NAD-27 and NAD-83 are significant and cannot be ignored. At Bozeman, Montana the difference is about 62 meters in longitude and 10 meters in latitude.

GPS data are based on the 1984 World Geodetic System (WGS-84) reference ellipsoid. The differences between GRS-80 (the ellipsoid on which NAD-83 is based) and WGS-84 are very small, and, for weed mapping work, they can be considered equal. Therefore, GPS data can be plotted on a USGS topographic map based on the NAD-83 horizontal datum without a conversion. But, if you tried to plot GPS collected data on a USGS topographic map based on the NAD-27 horizontal datum, the data would appear 62 meters to the west and 10 meters to the south of where they actually occur.

The National Geodetic Survey (NGS) provides software to convert coordinates between datums, and the more sophisticated GIS programs contain utilities that can perform these conversions. Your GPS software should also have this capability. The conversions incorporated into GIS and GPS software are often not as accurate as those provided by the NGS, but, in most cases, they are probably accurate enough for weed mapping work.

When preparing to plot the GPS-captured weed infestation data on a topographic map, the projection of the map must also be considered. The datum and projection used for a USGS topographic map are printed in the lower left

Before combining data from different sources (e.g., digitized hand-drawn infestation boundaries, GPS-collected data and digital base maps) in GIS, they must be converted to the same datum, projection and coordinate system.

corner of the map. A good GIS will contain definitions for all common map projections, and your GPS software should also have the capability to convert among coordinate systems. You must convert your GPS data to the proper map projection before it will overlay correctly on the base map.

In addition, the geodetic (latitude, longitude and height) GPS coordinates must be converted to the coordinate system used on the topographic map. Most GPS software allows you to export your data in a number of coordinate systems: geographic (latitude/longitude), UTM, state plane, etc.

If your mapping application requires elevation, you must understand the difference between GPS derived "elevation" and elevation above mean sea level. GPS height measurements are not in the normally used height system; they refer to height above the WGS-84 reference ellipsoid (sometimes called HAE, or height above ellipsoid). Elevations from topographic maps or survey control benchmarks are heights relative to the geoid (an undulating[9] surface based on gravity measurements and associated with mean sea level).

In order to derive elevation above sea level from GPS height, the difference between the ellipsoid and the geoid must be known. This varies across the surface of the earth. Throughout the continental United States the geoid is below the ellipsoid. In Bozeman, Montana the difference is approximately 10.5 meters, and converting ellipsoidal height (the height computed by a GPS receiver) to elevation above sea level requires adding the 10.5 meters. The NGS distributes a mathematical model of the geoid surface, called GEOID96, which provides an estimate of the geoid height (the difference between the geoid and the ellipsoid, also called geoidal separation) for any position in North America. Your GPS software should also have the ability to convert from ellipsoidal height to geoidal height (height above sea level). Although these conversions are often not as accurate as those provided by the NGS, they are usually accurate enough for weed mapping work.

When should GPS be used?

GPS is the most advanced, efficient and accurate tool for weed mapping. It is also the most expensive in terms of equipment needs and time involved in the inventory. However, the high level of accuracy justifies the initial cost in many cases. For small project areas, or to identify newly invading weed species, GPS is the best mapping tool. For large project areas, walking or driving the perimeters of all weed infestations may not be practical. Estimates of infestation boundaries and decreased accuracy may have to be accepted in those situations. To reduce the costs associated with GPS mapping, equipment could be shared. Additionally, many government agencies provide base station correction files. If these are available at no charge in your area, initial expense would be limited to the purchase of roving GPS receivers. As GPS equipment costs decrease, this weed mapping method will become more affordable.

[9] This contrasts with an ellipsoid, which is a smooth surface.

Combining Data Recording Methods

Data recording methods described in the previous sections can be used alone or in combination with one another. Some examples of combining data recording methods are:

1) Weed infestations are hand-drawn on USGS topographic maps and later digitized and incorporated into a computer mapping system.
2) Infestation boundaries are drawn manually in a computer mapping program and plotted along with digital base maps from the U.S. Census Bureau TIGER files.
3) Weed infestation locations and attributes are recorded using a GPS receiver and imported into a computer mapping program; after performing the proper conversions, the data are plotted on mylar overlays to match with a USGS topographic map.
4) Data collected using a GPS receiver in one location are combined in the computer system with data digitized from hand-drawn maps from another location; they are then laid over a digital soils map available from the Natural Resources Conservation Service (NRCS).

Each scenario requires attention to issues of scale, datums, projections and coordinate systems.

Software Compatibility Considerations

The *Montana Noxious Weed Survey and Mapping System* uses *ARC/INFO* and *ArcView* software for the statewide weed database. Statewide weed data will be based on a scale of 1:100,000. Data captured at more detailed scales (e.g., 1:24,000) may be incorporated into the statewide weed database. However, when these data are plotted on statewide maps, some detail will be lost. Data captured at scales less detailed than 1:100,000 will not be usable by the statewide weed database. Statewide maps showing infestations of Montana's Category 1, 2 and 3 noxious weeds will be produced. These maps may be plotted at various scales to fit different documents and presentation needs.

Digital weed data may be submitted to the *Montana Noxious Weed Survey and Mapping System* in one of the following formats (most computer mapping programs allow data to be exported in several different formats):

1) ArcView (SHP),
2) ARC/INFO coverages,
3) ARC/INFO ASCII (E00),
4) Atlas GIS (AGF),
5) Atlas ASCII (BNA),
6) CountyCAD, Arc/CAD, other CAD systems (DXF), and
7) Map Info (MIF/MID).

Visit our Web site for links to digital data available for Montana. Be sure to check out the metadata for any digital data set you intend to use.

Digital Base Layers Available for Computer Mapping

Most computer mapping programs are bundled with a limited set of geographic files such as state and county boundaries, cities and some roads. Additional geographic boundaries are available from computer mapping program manufacturers, third party vendors and government agencies. The Natural Resource Information Center (NRIS) at the Montana State Library in Helena maintains a current inventory of available digital base layers for Montana including transportation, soils, hydrography, topography and others. These layers are in various states of completion. The NRIS inventory lists a description of the layer, responsible agency, scale, status and other pertinent information. Other sources of digital base layers are the TIGER files available from the U.S. Census Bureau and remote sensing data available from various sources (digital orthophotos, satellite imagery, etc.). These digital layers are in various formats and most can be imported into computer mapping programs using conversion software provided by the mapping program manufacturer. The Internet is another source for digital geographic files, and many can be obtained for free. Be sure you can find out the scale and accuracy of any digital data you intend to use.

Metadata

Along with the digital data you should receive documentation, called metadata (data about data), that tells what the database contains, where the data came from, how accurate the data are, and other information you need to know in order to use the data such as lookup tables for attribute codes and specific information about feature coordinates. Any time a database is modified, the metadata are updated with information about who worked on it and what was done to it. These metadata provide information to potential users that can help them determine whether a data set meets their needs. Starting in 1995 federal agencies are required to document their data according to the National Spatial Data Infrastructure (NSDI) standards. Local governments and private organizations should also document geographic data layers they create so they can be shared (avoiding duplication of effort) and so individuals interested in using the data layers for other purposes understand their characteristics and limitations. The use of metadata can alleviate misinterpretation and misrepresentation of spatial data.

When contributing data to the *Montana Noxious Weed Survey and Mapping System*, weed managers fill out a metadata form (Appendix A), which provides critical information about their data that allows us to process and present it accurately.

National Spatial Data Infrastructure (NSDI)

The NSDI standards require that metadata be accessible to the National Geospatial Data Clearinghouse, a distributed network that allows federal data providers such as the USGS and BLM to list the data they have available with instructions on how to obtain it. Having a single clearinghouse makes access to spatial data easier for potential users. Local governments and private organizations will likely take advantage of the clearinghouse to locate and obtain federal data and to distribute their own data.

Summary

Using GIS and GPS technologies to map weeds can appear complicated and may be intimidating for some people. There are several critical issues that must be addressed. However, being aware of potential problems and paying careful attention to important details will ensure that the data you collect are accurate, complete and useful to you and others. If you plan to map weeds using these new technologies, and to submit your data to the statewide weed mapping system, please contact us at the address listed on page 9 or visit our Web site at http://www.montana.edu/places/mtweeds. We can provide you with a weed mapping handbook that describes specific details of the mapping process. It will help you avoid some of the pitfalls that other new users have encountered, and learn some of the techniques that can help make your mapping work go smoothly.

Mapping noxious weed infestations is not as difficult as it seems if you are careful. Help is always available!

More information

For more information about noxious weeds, see the MSU Extension Service MontGuide *Understanding Montana's Noxious Weed Law* (MT 9605 AG).

Appendix A, Metadata form. *Updated, Nov. 5, 1997*

The information in this publication is being continuously updated. For the most recent news, information and metadata forms, please visit our Web site at: http://www.montana.edu/places/mtweeds